Appendix H

Stormwater System Design

Purpose

The purpose of this calculation is to provide a preliminary analysis of piping size and headloss for the new (proposed) drainage system to be installed as part of the Skykomish Levee Remediation. These calculations address a drainage system for an area that is encompassed by the railroad line to the south, the levee crest on the north, 5th Street to the east, and McCowen's house on West River Road on the west. The area west of McCowen's house is drained by a drainage ditch and the Town does not plan to include this area in the proposed drainage system (Personal communication, Gary West, 15 December 2005).

The layout of a preliminary system is given in plan and profile in Figure 1. The analysis concentrates on verifying the pipe sizes and headlosses in the outfall and trunk line to be installed under West River Road.

Given

Per the Town's Resolution, the analysis and the preliminary design is in general conformance with the *King County, Washington, Surface Water Design Manual* (**SWDM**, King County, Department of Natural Resources and Parks, 2005) and the *King County Road Standards 1993* (**KCRS**, King County, Department of Transportation, 1993).

Per the calculation of runoff (Calculation by RETEC of Stormwater Runoff to Drainge System, 21 December 2005), the peak runoff for the 25-year return frequency storm event, and the design flow for the conveyance system, is 7.0 cfs (3,140 gpm).

The components of the drainage conveyance system are discussed below. Where applicable, the appropriate SWDM or KCRS design criteria are referenced.

Catch Basins

Per KCRS (7.04A), a catch basin shall be spaced no more than 150 feet apart. Catch Basins Type 1 (per King County Standard Drawing No. 2-003) are to be installed adjacent to the curb at the toe of the retaining wall. While KCRS (7.04B) prefers that catch basins be used for road surfaces, it does not rule out the use of curb inlets.

Catch Basin Drain (Lateral) Pipe

Each catch basin is to be connected by an 8-inch lateral to a nearby manhole or an adjacent catch basin. If two adjacent catch basins are interconnected by an 8-inch lateral pipe, the downstream catch basin will be connected by a 12-inch lateral pipe to a nearby manhole.

SWDM (4.2.1.1, Pg. 4-11) requires a minimum of 2 feet of cover over drain pipe. The lateral drain pipes will be subjected to snowplow loads (assumed H20) periodically. Therefore, the IE of the exiting drain pipe from the catch basin will be at least 32 inches below the structure rim elevation.

Manholes

The manholes are to be 48-inch diameter King County Standard Manholes Type 1 (Drawing No. 2-007).

Manhole-to-Manhole (Trunk) Drain Pipe

The trunk drain line is to run between, and interconnect, manholes. It is to run parallel to the levee for 630 feet and needs to carry increasing flows from 0.83 cfs at 5th Street to 7.00 cfs at the outfall.

Oil/Water Separator

To help maintain surface water quality in the river, an oil/water separator is to be located between the first manhole and the outfall. The simplest structure is the 72-inch diameter baffle type (FROP-B) flow restrictor/oil pollution control device in a manhole per King County Standard Drawing No. 2-027.

Check Valve

To prevent backflow in the conveyance system, a check valve is to be located between the oil/water separator and the outfall. The check valve is to be a Red Valve duck-billed Series 39 valve, or equivalent. For easy maintenance and replacement, the valve will be installed in an assessable underground concrete vault.

Outfall

The outfall is to be a tightline pipe from the oil/water separator, through the check valve, and under the levee, to an energy dissipating rock pad near the toe of the levee into the South Fork of the Skykomish River. To prevent large debris and children from entering the outfall pipe, a metal grating will be installed over the end of the outfall pipe. To prevent floating debris from damaging the end of the outfall, large guardian rocks will be placed around the end of the outfall.

Assumptions

A number of options are available to the design of the drainage system. These include two configurations (a four-manhole and a six-manhole configuration), six pipe sizes (from 12 to 30 inches), and two trunk line slopes (0.2 % to 0.5 %). The plan is to optimize the drainage system design in the analysis.

Using KCRS criteria, seven catch basins are needed to intercept surface drainage along the levee. One catch basin (CB) each is assumed to be located at the north end of 5th Street Arterial CB6), one at the bend midway between the north ends of 5th and 6th Streets (CB5), one at the north end of 6th Street (CB4), three evenly spaced between the north end of 6th Street and the west end of the levee retaining wall (CBs 3, 2, and 1), and one at the end of the temporary road traversing Lyderson's property (CB0).

The flow into each catch basin is assumed to be proportional to the areas of the subsections of the total drainage area. The sub-areas and resulting flows to the individual catch basins is presented in Table 1.

Table 1. The Apportioned Catch Basin Flows Based on Percentage of Drainage Area.

Catch Basin Number	Portion of Total Area (%)	Apportioned Flow to CB (cfs)
CB0	15	1.05
CB1	12	0.84
CB2	13	0.91
CB3	13	0.91
CB4	19	1.33
CB5	16	1.12
CB6	12	0.84

The Town has expressed a preference (Personal Communication, Gary West, 15 December 2005) that all pipe material be HDPE pipe, corrugated on the outside and smooth on the inside (King County's designation of LCPE pipe per SWDM, Section 4.2.1.1). The calculations assume this material in subsequent calculations.

The main drainage trunk pipe will be analyzed for minimum slope down to the west of 0.2% and a maximum of 0.5%. The 0.2% slope is the SWDM (4.2.1, Pg. 4-11) and KCRS minimum allowable slope. The maximum slope of 0.5% conforms to the topography. West River Road drops 3 feet (927.2 feet to 924.2 feet) in the 640 feet along the length of the levee. This is a slope of 0.5% (0.0047 to be more precise).

The levee remediation will require removal of the existing conveyance system up to about 100 feet south of the levee and installation of a new drainage system with reconstruction of the levee. The existing drainage system, within the confines of the levee remediation zone and intercepted by the barrier wall, is assumed to consist of the following:

- A 12-inch concrete pipe with an invert elevation (IE per NAVD88) of 924.76 feet from a catch basin in 5th Street Arterial extending north about 140 feet through the existing levee to an 18-inch CMP outfall with an IE of 919.68 feet;
- A 6-inch concrete pipe with an IE of 923.20 feet from a catch basin in 6th Street extending north through the existing levee, but with no visible outfall;
- An 8-inch concrete pipe with an IE of 923.60 feet from the same 6th Street catch basin as above extending northwest about 100 feet through the existing levee to an 8-inch CMP outfall with an IE of 918.26 feet;
- An 8-inch concrete pipe with an IE of 924.76 feet from a different catch basin in 6th Street extending north about 60 feet to a catch basin at the end of 6th Street and West River Road and an IE of 923.44 feet;
- An 8-inch concrete pipe coming into the above catch basin (at the end of 6th Street and West River Road) from the southeast with an IE of 923.49 feet;
- A 12-inch CMP with an IE of 923.54 feet from the same 6th Street and West River Road catch basin as above extending north about 50 feet through the existing levee to an 18-inch CMP outfall with an IE of 921.39 feet.

Construction of the new surface water drainage system is anticipated to include the following steps:

- Intercepting existing pipe and conveying them to manholes;
- Installing seven catch basins along West River Road at the Town-side toe of the levee;
- Installing additional catch basins south of the levee as the limits of the excavation require;
- Installing 8-inch to 12-inch lateral pipe from each inlet/catch basin to a manhole;
- Installing four or six 48-inch manholes along West River Road;
- Installing 12-inch to 24-inch trunk pipe connecting the manholes;
- Installing a 72-inch manhole-type oil/water separator upstream between the last manhole and the outfall;
- Installing a check valve between the oil/water separator and the outfall;

- Installing an 18-inch to 30-inch outfall pipe through the levee and into the South Fork of the Skykomish River.

The four-manhole configuration is assumed to consist of the following consecutive elements:

- 42-foot long outfall with an in-line check valve,
- 6-foot diameter oil/water separator,
- 10-foot long trunk pipeline,
- 4-foot diameter manhole (MH1),
- 364-foot long trunk pipeline,
- 4-foot diameter manhole (MH2),
- 164-foot long trunk pipeline,
- 4-foot diameter manhole (MH3),
- 100-foot long trunk pipeline,
- 4-foot diameter manhole (MH4).

The six-manhole configuration is assumed to consist of the following consecutive elements:

- 42-foot long outfall with an in-line check valve,
- 6-foot diameter oil/water separator,
- 10-foot long trunk pipeline,
- 4-foot diameter manhole (MH1),
- 160-foot long trunk pipeline,
- 4-foot diameter manhole (MH2),
- 118-foot long trunk pipeline,
- 4-foot diameter manhole (MH3),
- 78-foot long trunk pipeline,
- 4-foot diameter manhole (MH4),
- 164-foot long trunk pipeline,
- 4-foot diameter manhole (MH5),
- 100-foot long trunk pipeline,
- 4-foot diameter manhole (MH6).

The proposed rim elevations of the structures for each configuration are presented in Table 2. The four-manhole configuration is presented schematically in Figure 2 and the six-manhole configuration in Figure 3.

For calculation purposes, the water elevation in the river is assumed to have an annual high water level of 922.8 feet (NAVD88) and may drop below elevation 919.0 feet.

Table 2. Proposed Rim Elevations (in Feet, NAVD) of Oil/Water Separator and Manholes Along West River Road.

Structure	4-Manhole Option	6-Manhole Option
Oil/Water Separator	925.00*	925.00*
Manhole 1	924.20	924.20
Manhole 2	925.20	924.40
Manhole 3	926.50	925.00
Manhole 4	927.20	925.40
Manhole 5	-	926.40
Manhole 6	-	927.20

* Baffle elevation is 923.50 feet.

Calculations

Per SWDM (4.2.1.1, Pg 4-11), the minimum full pipe flow velocity shall be 3 feet per second (fps), the minimum pipe slope shall be 0.2% for 12-inch pipe and larger (0.5% for 8-inch pipe), and the maximum length between structures shall be 300 feet, and 150 feet for grades less than 1% (KCRS, 7.04.A).

Using the above restrictions and the uniform flow analysis method, a preliminary analysis (pipe sizes, invert elevations, and backwater levels) of the trunk pipes between manholes and the outfall are calculated. Analyses are performed for pipes flowing full, associated with a river level higher than 921.0 feet, and for pipes flowing partially full, associated with river level lower than 919.0 feet.

The initial screening of pipe sizes, invert elevations, and backwater levels is analyzed using the Darcy-Weisbach methods for backwater calculations. The calculations for pipes flowing full, along with their sources and the equations upon which they are based, are presented on spreadsheets in Attachment A for the outfall to MH1, in Attachment B for the four-manhole configuration, and in Attachment C for the six-manhole configuration.

The differential headwater elevations and slope elevations for each run of pipe are summarized in Tables 3 and 4 for the four-manhole and six-manhole configurations, respectively. The differential headwater elevations are obtained by adding the minor headlosses, and pipe friction for each run of pipe between structures.

The elevation of the hydraulic grade line (headwater level) at each structure is obtained by adding the respective differential headwater elevations and slope elevations to the tailwater elevation of the river. An optimum trunk pipeline configuration is obtained by selecting the pipe sizes and slopes whose sequential addition of differential headwater elevations and slope elevations do not exceed the sequential manhole rim elevations.

Table 3. Differential Headwater Elevations (in Feet) and Slope Elevations (in Feet) for Each Run of Pipe for the Four-Manhole Configuration.

Pipe Run	**12"**	**15"**	**18"**	**21"**	**24"**	**30"**	**0.2% Slope**	**0.5% Slope**
Outfall to Oil/Water Separator			1.67	0.89	0.53	0.30	0.09	0.22
Oil/Water Separator Baffle Orifice	1.23	0.51	0.24	0.13	0.08	0.03	-	-
Oil/Water Separator to Manhole 1			0.37	0.19	0.12	0.04	0.03	0.08
Manhole 1 to Manhole 2	3.06	1.08	0.44				0.74	1.84
Manhole 2 to Manhole 3	0.40	0.14					0.34	0.84
Manhole 3 to Manhole 4	0.06						0.21	0.52

To keep from overflowing at the manhole lids (see Table 2 for rim elevations) during an annual high river flow (elevation 922.7 feet NAVD), an optimum four-manhole configuration has the following trunk pipeline sizes:

- 24-inch diameter outfall with an IE of 919.0 feet at a slope of 0.2% from the river to manhole 1 (MH1). This includes a 24-inch diameter in-line check valve and the oil/water separator.
- 18-inch diameter trunk pipe at a slope of 0.2% from MH1 to MH2,
- 12-inch diameter trunk pipe at a slope of 0.5% from MH2 to MH3,
- 12-inch diameter trunk pipe at a slope of 0.5% from MH3 to MH4.

Table 4. Differential Headwater Elevations (In Feet) and Slope Elevations (in Feet) for Each Run of Pipe for the Six-Manhole Configuration.

Pipe Run	**12"**	**15"**	**18"**	**21"**	**24"**	**30"**	**0.2% Slope**	**0.5% Slope**
Outfall to Oil/Water Separator			1.67	0.89	0.53	0.30	0.09	0.22
Oil/Water Separator Baffle Orifice	1.23	0.51	0.24	0.13	0.08	0.03	-	-
Oil/Water Separator to Manhole 1			0.37	0.19	0.12	0.04	0.03	0.08
Manhole 1 to Manhole 2	2.41	0.89	0.40	0.19	0.10		0.33	0.82
Manhole 2 to Manhole 3	1.42	0.51	0.23	0.12			0.24	0.61
Manhole 3 to Manhole 4	0.70	0.26	0.12				0.16	0.41
Manhole 4 to Manhole 5	0.41	0.14	0.07				0.34	0.84
Manhole 5 to Manhole 6	0.07	0.02					0.21	0.52

To keep from overflowing at the manhole lids (see Table 2 for rim elevations) during an annual high river flow (elevation 922.7 feet NAVD), an optimum six-manhole configuration has the following trunk pipeline sizes:

- 24-inch diameter outfall with an IE of 919.0 feet at a slope of 0.2% from the river to manhole 1 (MH1). This includes a 24-inch diameter in-line check valve and the oil/water separator.
- 18-inch diameter trunk pipe at a slope of 0.2% from MH1 to MH2,
- 18-inch diameter trunk pipe at a slope of 0.2% from MH2 to MH3,
- 18-inch diameter trunk pipe at a slope of 0.2% from MH3 to MH4,
- 12-inch diameter trunk pipe at a slope of 0.5% from MH4 to MH5,
- 12-inch diameter trunk pipe at a slope of 0.5% from MH5 to MH6.

For comparison, the SWDM backwater analysis method was applied to both configurations. The analyses are presented on spreadsheets in Attachments D and E for the four-manhole and six-manhole configurations, respectively. The resulting headwater elevations are about 15% higher (~0.30 feet) than those calculated by the Darcy-Weisbach methods above. This indicates that the SWDM backwater analysis method is the more conservative method of calculation. It also indicates that the water level in the river can rise to an elevation of 923.5 feet for either configuration before it starts to overflow the rims of the manholes on West River Road.

For river levels below 919.0 feet (NAVD), the outfall and portions of the trunk pipelines flow only partially full. This means that the analysis needs to use culvert flow methods to evaluate. Partial flow culvert analysis is not exact and requires the use of SWDM nomographs and empirical curves in a series of trial-and-error calculations. For each pipe segment, the tailwater elevation is calculated using the critical depth from Figure 4.3.1.F (Pg. 4-49). The tailwater elevation results are presented in Table 5. Again, the SWDM backwater analysis method was applied to both configurations. The calculations are presented in Attachments F and G. In all cases, the hydraulic grade line is below the crown of the pipe at the outlet, or exit end, and just above the crown at the inlet, or entrance, end. This means that all the pipe segments flow partially full and the outlet end of the pipe and flow full at the inlet end.

Table 5. Tailwater Elevation Calculations for both Configurations.

Segment		Pipe Diameter [D] (in)	Pipe Discharge [Q] (cfs)	Critical Depth-Diameter Ratio	Critical Depth [d_c] (ft)	Outlet Invert Elevation (ft)	Tailwater Elevation* (ft)
4-MH Config.	Outfall - O/W Separator	24	7.00	0.47	0.94	919.00	920.47
	O/W Separator - MH1	24	7.00	0.47	0.94	919.09	920.56
	MH1 – MH2	18	4.20	0.39	0.58	919.12	920.16
	MH2 – MH3	12	1.96	0.58	0.58	919.86	920.65
	MH3 – MH4	12	0.84	0.37	0.37	920.70	921.38
6-MH Configuration	Outfall - O/W Separator	24	7.00	0.47	0.94	919.00	920.47
	O/W Separator - MH1	24	7.00	0.47	0.94	919.09	920.56
	MH1 – MH2	18	5.11	0.59	0.88	919.12	920.31
	MH2 – MH3	18	4.20	0.51	0.76	919.45	920.58
	MH3 – MH4	18	3.29	0.46	0.69	919.69	920.78
	MH4 – MH5	12	1.96	0.58	0.58	919.85	920.64
	MH5 – MH6	12	0.84	0.37	0.37	920.69	921.38

* Tailwater elevation = Invert elevation + $(D+d_c)/2$.

Discussion

The preliminary details of the structures and pipelines are given in Tables 6 and 7, respectively. These details will cause some revision to Figure 1 before it is incorporated into the final drawing set.

There is a potential to eliminate two manholes along the levee by interconnecting two sets of catch basins. CB4 could be interconnected to CB3 with an 8-inch lateral pile and CB5 could be interconnected to CB6 with an 8-inch lateral. Then CBs 3 and 6 could be connected to here adjacent manholes by 12-inch lateral pipes.

Ecology may determine that the manhole-type oil/water separator is insufficient, in which case a larger vault-type baffle oil/water separator or coalescing plate separator will be required.

Table 6. Preliminary Structure Details for the Skykomish Drainage System.

Structure		Rim Elevation (ft)	Invert Elevation In (ft)	Invert Elevation Out (ft)
Four-Manhole Configuration	O/W Separator	925.00	919.10	919.09
	CB0	923.50		920.50
	MH 1	924.20	919.13	919.12
	CB 1	924.40		921.40
	CB2	924.44		921.44
	MH 2	925.20	919.87	919.86
	CB3	924.96		921.96
	CB4	925.51		922.51
	MH 3	926.50	920.71	920.70
	CB5	926.38		923.38
	MH 4	927.20	912.23	921.22
	CB6	927.10		924.10
Six-Manhole Configuration	O/W Separator	925.00	919.10	919.09
	CB0	923.50		920.50
	MH 1	924.20	919.13	919.12
	CB 1	924.40		921.40
	MH 2	924.40	923.02	922.98
	CB 2	924.44		921.44
	MH 3	925.00	921.32	921.28
	CB 3	924.96		921.96
	MH 4	925.40	920.91	920.89
	CB 4	925.51		922.51
	MH 5	926.40	920.31	920.29
	CB 5	926.38		923.38
	MH 6	927.20	919.51	919.49
	CB 6	927.10		924.10

Table 7. Preliminary Pipe Details for the Skykomish Drainage system.

Pipe Segment		Invert Elevation In (ft)	Invert Elevation Out (ft)	Inside Diameter (in)	Length (ft)	Slope (%)
Four-Manhole Configuration	O/W Separator - Outfall	919.09	919.00	24	42	0.2
	MH1 - O/W Separator	919.12	919.10	24	10	0.2
	CB0 - MH1	920.50	919.20	8	130	1
	CB1 - MH1	919.90	919.75	8	15	1
	CB2 - CB1	921.44	919.94	12	150	1
	MH2 - MH1	919.86	919.13	18	364	0.2
	CB3 - CB4	921.96	920.80	8	116	1
	CB4 - MH2	920.75	920.40	12	35	1
	MH3 - MH2	920.70	919.87	12	164	0.5
	CB5 - MH3	923.38	923.32	8	6	1
	MH4 - MH3	921.22	920.71	12	100	0.5
	CB6 - MH4	924.10	924.02	8	8	1
Six-Manhole Configuration	O/W Separator - Outfall	919.09	919.00	24	42	0.2
	MH1 - O/W Separator	919.12	919.10	24	10	0.2
	CB0 - MH1	920.50	919.20	8	130	1
	CB1 - MH1	919.90	919.75	8	15	1
	MH2 - MH1	919.45	919.13	18	160	0.2
	CB2 - MH2	921.44	921.38	8	6	1
	MH3 - MH2	919.69	919.46	18	118	0.2
	CB3 - MH3	921.96	921.90	8	6	1
	MH4 - MH3	919.85	919.70	18	78	0.2
	CB4 - MH4	920.75	920.40	8	35	1
	MH5 - MH4	920.69	919.86	12	164	0.5
	CB5 - MH5	923.38	923.32	8	6	1
	MH6 - MH5	921.21	920.70	12	100	0.5
	CB6 - MH6	924.10	924.02	8	8	1

References

King County. *King County Road Standards 1993*. King County Department of Transportation, Road Services Division, King County, Washington.

King County. *King County, Washington, Surface Water Design Manual*. King County Department of Natural Resources and Parks, King County, Washington, January 24, 2005.

Skykomish Levee Drainage System

Pipe Headloss from Outfall from Discharge to O/W Separator:

Step	Item/Description	Symbol	Unit	Calculations			
1	Calculation Identification	-	-	Outfall-O/W	Outfall-O/W	Outfall-O/W	Outfall-O/W
2	Flow rate	Q	cfs	7.00	7.00	7.00	7.00
3	Pipe diameter	d	in	18	21	24	30
4	Pipe length	L	ft	42	42	42	42
5	Pipe area	A	ft^2	1.767	2.405	3.142	4.909
6	Average flow velocity	v	ft/sec	3.96	2.91	2.23	1.43
7	Kinematic viscosity	n	ft^2/sec	0.0000190	0.0000190	0.0000190	0.0000190
8	Reynold's number	N_{Re}	-	312726	268050	234544	187635
9	Friction factor	f	-	0.016	0.017	0.017	0.018
10	Pipe headloss	h_L	ft	0.11	0.05	0.03	0.01

1-4	User input of calculation identification, flow rate, pipe diameter, and pile length.
5	$A = pd^2/4$; note that if diameter is in inches, then d = diameter/12.
6	$v = Q/A$
7	For kinematic viscosity, see Tuma Table A.60, or equivalent.
8	$N_{Re} = dv/n$
9	For friction factor, see Tuma Table A.65, or equivalent.
10	$h_L = fLv^2/2gd$

Tuma, Jan J. *Handbook of Physical Calculations* . Second Edition, McGraw-Hill Book Company, New York, 1983.

Minor Headloss from Outfall from Discharge to O/W Separator:

Step	Item/Description	Symbol	Unit	Calculations					
1	Calculation Identification	-	-	Outfall Out	CV	O/W Out	Outfall Out	CV	O/W Out
2	Flow rate	Q	cfs	7.00	7.00	7.00	7.00	7.00	7.00
3	Pipe diameter	d	in	18	18	18	21	21	21
4	Pipe area	A	ft^2	1.767	1.767	1.767	2.405	2.405	2.405
5	Average flow velocity	v	ft/sec	3.96	3.96	3.96	2.91	2.91	2.91
6	Minor loss coefficient	K	-	1.00	5.00	0.42	1.00	5.00	0.38
7	Pipe headloss	h_L	ft	0.24	1.22	0.10	0.13	0.66	0.05

1-3	User input of calculation identification, flow rate, pipe diameter, and pile length.
4	$A = pd^2/4$; note that if diameter is in inches, then d = diameter/12.
5	$v = Q/A$
6	For minor loss coefficient, see Tuma Pages 188-189, or equivalent.
7	$h_L = Kv^2/2g$

Minor Headloss from Outfall from Discharge to O/W Separator (Cont.):

Step	Item/Description	Symbol	Unit	Calculations					
1	Calculation Identification	-	-	Outfall Out	CV	O/W Out	Outfall Out	CV	O/W Out
2	Flow rate	Q	cfs	7.00	7.00	7.00	7.00	7.00	7.00
3	Pipe diameter	d	in	24	24	24	30	30	30
4	Pipe area	A	ft^2	3.142	3.142	3.142	4.909	4.909	4.909
5	Average flow velocity	v	ft/sec	2.23	2.23	2.23	1.43	1.43	1.43
6	Minor loss coefficient	K	-	1.00	5.00	0.36	1.00	5.00	0.34
7	Pipe headloss	h_L	ft	0.08	0.39	0.03	0.03	0.16	0.01

Minor Headloss at Oil/Water Separator:

Step	Item/Description	Symbol	Unit	Calculations					
1	Calculation Identification	-	-	Orifice	Orifice	Orifice	Orifice	Orifice	Orifice
2	Flow rate	Q	cfs	7.00	7.00	7.00	7.00	7.00	7.00
3	Pipe diameter	d	in	12	15	18	21	24	30
4	Pipe area	A	ft^2	0.785	1.227	1.767	2.405	3.142	4.909
5	Average flow velocity	v	ft/sec	8.91	5.70	3.96	2.91	2.23	1.43
6	Minor loss coefficient	K	-	1.00	1.00	1.00	1.00	1.00	1.00
7	Pipe headloss	h_L	ft	1.23	0.51	0.24	0.13	0.08	0.03

Pipe Headloss from O/W Separator to MH1:

Step	Item/Description	Symbol	Unit	Calculations			
1	Calculation Identification	-	-	O/W-MH1	O/W-MH2	O/W-MH3	O/W-MH4
2	Flow rate	Q	cfs	7.00	7.00	7.00	7.00
3	Pipe diameter	d	in	18	21	24	30
4	Pipe length	L	ft	10	10	10	10
5	Pipe area	A	ft^2	1.767	2.405	3.142	4.909
6	Average flow velocity	v	ft/sec	3.96	2.91	2.23	1.43
7	Kinematic viscosity	n	ft^2/sec	0.0000190	0.0000190	0.0000190	0.0000190
8	Reynold's number	N_{Re}	-	312726	268050	234544	187635
9	Friction factor	f	-	0.016	0.017	0.017	0.018
10	Pipe headloss	h_L	ft	0.03	0.01	0.01	0.00

Minor Headloss from O/W Separator to MH1:

Step	Item/Description	Symbol	Unit	Calculations							
1	Calculation Identification	-	-	O/W In	MH1 Out	O/W In	MH1 Out	O/W In	MH1 Out	O/W In	MH1 Out
2	Flow rate	Q	cfs	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
3	Pipe diameter	d	in	18	18	21	21	24	24	30	30
4	Pipe area	A	ft^2	1.767	1.767	2.405	2.405	3.142	3.142	4.909	4.909
5	Average flow velocity	v	ft/sec	3.96	3.96	2.91	2.91	2.23	2.23	1.43	1.43
6	Minor loss coefficient	K	-	1.00	0.42	1.00	0.38	1.00	0.36	1.00	0.34
7	Pipe headloss	h_L	ft	0.24	0.10	0.13	0.05	0.08	0.03	0.03	0.01

Skykomish Levee Drainage System

Pipe Headloss from MH1 to MH4:

Step	Item/Description	Symbol	Unit	Calculations					
1	Calculation Identification	-	-	MH1-MH2	MH1-MH2	MH1-MH2	MH2-MH3	MH2-MH3	MH3-MH4
2	Flow rate	Q	cfs	4.20	4.20	4.20	1.96	1.96	0.84
3	Pipe diameter	d	in	12	15	18	12	15	12
4	Pipe length	L	ft	369	369	369	165	165	100
5	Pipe area	A	ft^2	0.785	1.227	1.767	0.785	1.227	0.785
6	Average flow velocity	v	ft/sec	5.35	3.42	2.38	2.50	1.60	1.07
7	Kinematic viscosity	n	ft^2/sec	0.0000190	0.0000190	0.0000190	0.0000190	0.0000190	0.0000190
8	Reynold's number	N_{Re}	-	281453	225162	187635	131345	105076	56291
9	Friction factor	f	-	0.015	0.016	0.016	0.017	0.018	0.019
10	Pipe headloss	h_L	ft	2.46	0.86	0.35	0.27	0.09	0.03

1-4	User input of calculation identification, flow rate, pipe diameter, and pile length.
5	$A = pd^2/4$; note that if diameter is in inches, then d = diameter/12.
6	$v = Q/A$
7	For kinematic viscosity, see Tuma Table A.60, or equivalent.
8	$N_{Re} = dv/n$
9	For friction factor, see Tuma Table A.65, or equivalent.
10	$h_L = fLv^2/2gd$

Tuma, Jan J. *Handbook of Physical Calculations*. Second Edition, McGraw-Hill Book Company, New York, 1983.

Minor Headloss from MH1 to MH2:

Step	Item/Description	Symbol	Unit	Calculations					
1	Calculation Identification	-	-	MH1-In	MH2-Out	MH1-In	MH2-Out	MH1-In	MH2-Out
2	Flow rate	Q	cfs	4.20	4.20	4.20	4.20	4.20	4.20
3	Pipe diameter	d	in	12	12	15	15	18	18
4	Pipe area	A	ft^2	0.785	0.785	1.227	1.227	1.767	1.767
5	Average flow velocity	v	ft/sec	5.35	5.35	3.42	3.42	2.38	2.38
6	Minor loss coefficient	K	-	0.92	0.42	0.81	0.38	0.70	0.36
7	Pipe headloss	h_L	ft	0.41	0.19	0.15	0.07	0.06	0.03

1-3	User input of calculation identification, flow rate, pipe diameter, and pile length.
4	$A = pd^2/4$; note that if diameter is in inches, then d = diameter/12.
5	$v = Q/A$
6	For minor loss coefficient, see Tuma Pages 188-189, or equivalent.
7	$h_L = Kv^2/2g$

Minor Headloss from MH2 to MH4:

Step	Item/Description	Symbol	Unit	Calculations					
1	Calculation Identification	-	-	MH2-In	MH3-Out	MH2-In	MH3-Out	MH3-In	MH4-Out
2	Flow rate	Q	cfs	1.96	1.96	1.96	1.96	0.84	0.84
3	Pipe diameter	d	in	12	12	15	15	12	12
4	Pipe area	A	ft^2	0.785	0.785	1.227	1.227	0.785	0.785
5	Average flow velocity	v	ft/sec	2.50	2.50	1.60	1.60	1.07	1.07
6	Minor loss coefficient	K	-	0.92	0.42	0.81	0.38	0.92	0.42
7	Pipe headloss	h_L	ft	0.09	0.04	0.03	0.02	0.02	0.01

Skykomish Levee Drainage System

Pipe Headloss from MH1 to MH2:

Step	Item/Description	Symbol	Unit	Calculations				
1	Calculation Identification	-	-	MH1-MH2	MH1-MH2	MH1-MH2	MH1-MH2	MH1-MH2
2	Flow rate	Q	cfs	5.11	5.11	5.11	5.11	5.11
3	Pipe diameter	d	in	12	15	18	21	24
4	Pipe length	L	ft	160	160	160	160	160
5	Pipe area	A	ft^2	0.785	1.227	1.767	2.405	3.142
6	Average flow velocity	v	ft/sec	6.51	4.16	2.89	2.12	1.63
7	Kinematic viscosity	n	ft^2/sec	0.0000190	0.0000190	0.0000190	0.0000190	0.0000190
8	Reynold's number	N_{Re}	-	342434	273948	228290	195677	171217
9	Friction factor	f	-	0.014	0.015	0.016	0.016	0.016
10	Pipe headloss	h_L	ft	1.47	0.52	0.22	0.10	0.05

1-4	User input of calculation identification, flow rate, pipe diameter, and pile length.
5	$A = pd^2/4$; note that if diameter is in inches, then d = diameter/12.
6	$v = Q/A$
7	For kinematic viscosity, see Tuma Table A.60, or equivalent.
8	$N_{Re} = dv/n$
9	For friction factor, see Tuma Table A.65, or equivalent.
10	$h_L = fLv^2/2gd$

Tuma, Jan J. *Handbook of Physical Calculations*. Second Edition, McGraw-Hill Book Company, New York, 1983.

Minor Headloss from MH1 to MH2:

Step	Item/Description	Symbol	Unit	Calculations							
1	Calculation Identification	-	-	MH1-In	MH2-Out	MH1-In	MH2-Out	MH1-In	MH2-Out	MH1-In	MH2-Out
2	Flow rate	Q	cfs	5.11	5.11	5.11	5.11	5.11	5.11	5.11	5.11
3	Pipe diameter	d	in	12	12	15	15	18	18	21	21
4	Pipe area	A	ft^2	0.785	0.785	1.227	1.227	1.767	1.767	2.405	2.405
5	Average flow velocity	v	ft/sec	6.51	6.51	4.16	4.16	2.89	2.89	2.12	2.12
6	Minor loss coefficient	K	-	1.00	0.42	1.00	0.37	1.00	0.35	1.00	0.34
7	Pipe headloss	h_L	ft	0.66	0.28	0.27	0.10	0.13	0.05	0.07	0.02

1-3	User input of calculation identification, flow rate, pipe diameter, and pile length.
4	$A = pd^2/4$; note that if diameter is in inches, then d = diameter/12.
5	$v = Q/A$
6	For minor loss coefficient, see Tuma Pages 188-189, or equivalent.
7	$h_L = Kv^2/2g$

Minor Headloss from MH1 to MH2 (Cont.):

Step	Item/Description	Symbol	Unit	Calculations	
1	Calculation Identification	-	-	MH1-In	MH2-Out
2	Flow rate	Q	cfs	5.11	5.11
3	Pipe diameter	d	in	24	24
4	Pipe area	A	ft^2	3.142	3.142
5	Average flow velocity	v	ft/sec	1.63	1.63
6	Minor loss coefficient	K	-	1.00	0.33
7	Pipe headloss	h_L	ft	0.04	0.01

Pipe Headloss from MH2 to MH4:

Step	Item/Description	Symbol	Unit	Calculations						
1	Calculation Identification	-	-	MH2-MH3	MH3-MH2	MH2-MH3	MH2-MH3	MH3-MH4	MH3-MH4	MH3-MH4
2	Flow rate	Q	cfs	4.20	4.20	4.20	4.20	3.29	3.29	3.29
3	Pipe diameter	d	in	12	15	18	21	12	15	18
4	Pipe length	L	ft	118	118	118	118	78	78	78
5	Pipe area	A	ft^2	0.785	1.227	1.767	2.405	0.785	1.227	1.767
6	Average flow velocity	v	ft/sec	5.35	3.42	2.38	1.75	4.19	2.68	1.86
7	Kinematic viscosity	n	ft^2/sec	0.0000190	0.0000190	0.0000190	0.0000190	0.0000190	0.0000190	0.0000190
8	Reynold's number	N_{Re}	-	281453	225162	187635	160830	220471	176377	146981
9	Friction factor	f	-	0.015	0.015	0.016	0.016	0.015	0.016	0.017
10	Pipe headloss	h_L	ft	0.79	0.26	0.11	0.05	0.32	0.11	0.05

Pipe Headloss from MH4 to MH6:

Step	Item/Description	Symbol	Unit	Calculations				
1	Calculation Identification	-	-	MH4-MH5	MH4-MH5	MH4-MH5	MH5-MH6	MH5-MH6
2	Flow rate	Q	cfs	1.96	1.96	1.96	0.84	0.84
3	Pipe diameter	d	in	12	15	18	12	15
4	Pipe length	L	ft	164	164	164	100	100
5	Pipe area	A	ft^2	0.785	1.227	1.767	0.785	1.227
6	Average flow velocity	v	ft/sec	2.50	1.60	1.11	1.07	0.68
7	Kinematic viscosity	n	ft^2/sec	0.0000190	0.0000190	0.0000190	0.0000190	0.0000190
8	Reynold's number	N_{Re}	-	131345	105076	87563	56291	45032
9	Friction factor	f	-	0.017	0.018	0.018	0.020	0.020
10	Pipe headloss	h_L	ft	0.27	0.09	0.04	0.04	0.01

Minor Headloss from MH2 to MH3:

Step	Item/Description	Symbol	Unit	Calculations							
1	Calculation Identification	-	-	MH2-In	MH3-Out	MH2-In	MH3-Out	MH2-In	MH3-Out	MH2-In	MH3-Out
2	Flow rate	Q	cfs	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20
3	Pipe diameter	d	in	12	12	15	15	18	18	21	21
4	Pipe area	A	ft^2	0.785	0.785	1.227	1.227	1.767	1.767	2.405	2.405
5	Average flow velocity	v	ft/sec	5.35	5.35	3.42	3.42	2.38	2.38	1.75	1.75
6	Minor loss coefficient	K	-	1.00	0.42	1.00	0.36	1.00	0.35	1.00	0.34
7	Pipe headloss	h_L	ft	0.44	0.19	0.18	0.07	0.09	0.03	0.05	0.02

Minor Headloss from MH3 to MH5:

Step	Item/Description	Symbol	Unit	Calculations							
1	Calculation Identification	-	-	MH3-In	MH4-Out	MH3-In	MH4-Out	MH3-In	MH4-Out	MH4-In	MH5-Out
2	Flow rate	Q	cfs	3.29	3.29	3.29	3.29	3.29	3.29	1.96	1.96
3	Pipe diameter	d	in	12	12	15	15	18	18	12	12
4	Pipe area	A	ft^2	0.785	0.785	1.227	1.227	1.767	1.767	0.785	0.785
5	Average flow velocity	v	ft/sec	4.19	4.19	2.68	2.68	1.86	1.86	2.50	2.50
6	Minor loss coefficient	K	-	1.00	0.42	1.00	0.36	1.00	0.35	1.00	0.42
7	Pipe headloss	h_L	ft	0.27	0.11	0.11	0.04	0.05	0.02	0.10	0.04

Minor Headloss from MH4 to MH6:

Step	Item/Description	Symbol	Unit	Calculations							
1	Calculation Identification	-	-	MH4-In	MH5-Out	MH4-In	MH5-Out	MH5-In	MH6-Out	MH5-In	MH6-Out
2	Flow rate	Q	cfs	1.96	1.96	1.96	1.96	0.84	0.84	0.84	0.84
3	Pipe diameter	d	in	15	15	18	18	12	12	15	15
4	Pipe area	A	ft^2	1.227	1.227	1.767	1.767	0.785	0.785	1.227	1.227
5	Average flow velocity	v	ft/sec	1.60	1.60	1.11	1.11	1.07	1.07	0.68	0.68
6	Minor loss coefficient	K	-	1.00	0.36	1.00	0.35	1.00	0.42	1.00	0.36
7	Pipe headloss	h_L	ft	0.04	0.01	0.02	0.01	0.02	0.01	0.01	0.00

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Step	Item/Description	Symbol	Unit	Calculations				
1	Pipe Segment - Outlet Structure	-	-	Outfall	O/W Sep	MH1	MH2	MH3
2	Pipe Segment - Inlet Structure	-	-	O/W Sep	MH1	MH2	MH3	MH4
3	Discharge	Q	cfs	7.00	7.00	4.20	1.96	0.84
4	Pipe Length	L	ft	42.00	10.00	364.00	164.00	100.00
5	Pipe Diameter	D	in	24	24	18	12	12
6	Manning "n" Value	n	-	0.012	0.012	0.012	0.012	0.012
7	Outlet Elevation	El_{out}	ft	919.00	919.09	919.12	919.86	920.70
8	Inlet Elevation	El_{in}	ft	919.09	919.12	919.86	920.70	921.22
9	Barrel Area	A	ft^2	3.14	3.14	1.77	0.79	0.79
10	Barrel Velocity	V	ft/sec	2.23	2.23	2.38	2.50	1.07
11	Barrel Velocity Head	h_V	ft	0.08	0.08	0.09	0.10	0.02
12	Tailwater Elevation	El_{TW}	ft	922.70	923.24	923.36	923.98	924.55
13	Friction Loss	h_f	ft	0.03	0.01	0.49	0.42	0.05
14	Entrance Hydraulic Grade Elevation	El_{entHGL}	ft	922.73	923.25	923.85	924.40	924.60
15	Entrance Loss Coefficient	K_{ent}	-	0.50	0.50	0.50	0.50	0.50
16	Entrance Head Loss	h_{ent}	ft	0.04	0.04	0.04	0.05	0.01
17	Exit Loss Coefficient	K_{ex}	-	1.00	1.00	1.00	1.00	1.00
18	Exit Head Loss	h_{ex}	ft	0.08	0.08	0.09	0.10	0.02
19	Other Loss Coefficient	K_o	-	5.00	0.00	0.00	0.00	0.00
20	Other Head Loss	h_o	ft	0.39	0.00	0.00	0.00	0.00
21	Outlet Control Elevation	$El_{outcont}$	ft	923.24	923.36	923.98	924.55	924.62
22	Inlet Control Elevation	El_{incont}	ft	921.09	921.12	921.36	921.70	922.22
23	Approach Velocity Head	h_{AV}	ft	0.00	0.00	0.00	0.00	0.00
24	Bend Loss Coefficient	K_b	-	0.00	0.00	0.00	0.00	0.00
25	Bend Head Loss	h_b	ft	0.00	0.00	0.00	0.00	0.00
26	Upstream Trunkline Discharge	Q_1	cfs	7.00	7.00	4.20	1.96	0.84
27	Upstream Lateral Discharge	Q_3	cfs	0.00	0.00	2.80	2.24	0.00
28	Junction Loss Coefficient	K_j	-	0.00	0.00	0.42	0.60	0.00
29	Junction Head Loss	h_j	ft	0.00	0.00	0.00	0.00	0.00
30	Headwater Elevation	El_{HW}	ft	923.24	923.36	923.98	924.55	924.62

* *King County, Washington, Surface Water Design Manual*. King County Department of Natural Resources, January 24, 2005.

1-8	User input of pipe segment, discharge (Q), pipe length (L), pipe diameter (D), roughness coefficient (n), outlet elevation (El_{out}), inlet elevation (El_{in}).
9	$A = p(D/12)^2/4$
10	$V = Q/A$
11	$h_V = V^2/2g$
12	User input of tailwater elevation (El_{TW}); or $(D+d_c)/2$, whichever is greater.
13	$h_F = L(nV)^2(D/48)^{-4/3}/2.22$
14	$El_{entHGL} = El_{TW} + h_F$
15	User input of entrance headloss coefficient (K_{ent}).
16	$h_{ent} = K_{ent}V^2/2g$
17	User input of exit headloss coefficient (K_{ex}).
18	$h_{exit} = K_{ex}V^2/2g$
19	User input of other headloss coefficient (K_o).
20	$h_o = K_oV^2/2g$
21	$El_{outcont} = El_{entHGL} + h_{ent} + h_{exit}$
22	User input of inlet control elevation (El_{incon}).
23	User input of approach velocity head, $h_{AV} = h_V$ in upstream segment.
24	User input of bend headloss coefficient.
25	$h_b = K_bh_{AV}$
26	User input of upstream trunkline discharge (Q_3).
27	User input of upstream lateral discharge (Q_1).
28	$Kj = (Q_3/Q_1)/[1.18+0.63(Q_3/Q_1)]$
29	$h_j = K_jh_{AV}$
30	El_{HW} = greater of $El_{outcont}$ or $El_{incont} - h_{AV} + h_b + h_j$

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Step	Item/Description	Symbol	Unit	Calculations						
1	Pipe Segment - Outlet Structure	-	-	Outfall	O/W Sep	MH1	MH2	MH3	MH4	MH5
2	Pipe Segment - Inlet Structure	-	-	O/W Sep	MH1	MH2	MH3	MH4	MH5	MH6
3	Discharge	Q	cfs	7.00	7.00	5.11	4.20	3.29	1.96	0.84
4	Pipe Length	L	ft	42.00	10.00	160.00	118.00	78.00	164.00	100.00
5	Pipe Diameter	D	in	24	24	18	18	18	12	12
6	Manning "n" Value	n	-	0.012	0.012	0.012	0.012	0.012	0.012	0.012
7	Outlet Elevation	El_{out}	ft	919.00	919.09	919.12	919.45	919.69	919.85	920.69
8	Inlet Elevation	El_{in}	ft	919.09	919.12	919.45	919.69	919.85	920.69	921.21
9	Barrel Area	A	ft^2	3.14	3.14	1.77	1.77	1.77	0.79	0.79
10	Barrel Velocity	V	ft/sec	2.23	2.23	2.89	2.38	1.86	2.50	1.07
11	Barrel Velocity Head	h_V	ft	0.08	0.08	0.13	0.09	0.05	0.10	0.02
12	Tailwater Elevation	El_{TW}	ft	922.70	923.24	923.36	923.88	924.17	924.32	925.08
13	Friction Loss	h_f	ft	0.03	0.01	0.32	0.16	0.06	0.42	0.05
14	Entrance Hydraulic Grade Elevation	El_{entHGL}	ft	922.73	923.25	923.68	924.04	924.23	924.74	925.13
15	Entrance Loss Coefficient	K_{ent}	-	0.50	0.50	0.50	0.50	0.50	1.50	2.50
16	Entrance Head Loss	h_{ent}	ft	0.04	0.04	0.06	0.04	0.03	0.15	0.04
17	Exit Loss Coefficient	K_{ex}	-	1.00	1.00	1.00	1.00	1.00	2.00	3.00
18	Exit Head Loss	h_{ex}	ft	0.08	0.08	0.13	0.09	0.05	0.19	0.05
19	Other Loss Coefficient	K_o	-	5.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Other Head Loss	h_o	ft	0.39	0.00	0.00	0.00	0.00	0.00	0.00
21	Outlet Control Elevation	$El_{outcont}$	ft	923.24	923.36	923.88	924.17	924.32	925.08	925.22
22	Inlet Control Elevation	El_{incont}	ft	921.09	921.12	920.95	921.19	922.35	921.69	922.21
23	Approach Velocity Head	h_{AV}	ft	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Bend Loss Coefficient	K_b	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Bend Head Loss	h_b	ft	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Upstream Trunkline Discharge	Q_1	cfs	7.00	5.11	4.20	3.29	1.96	0.84	0.84
27	Upstream Lateral Discharge	Q_3	cfs	0.00	1.89	0.91	0.91	1.33	1.12	0.00
28	Junction Loss Coefficient	K_j	-	0.00	0.26	0.16	0.20	0.42	0.66	0.00
29	Junction Head Loss	h_j	ft	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	Headwater Elevation	El_{HW}	ft	923.24	923.36	923.88	924.17	924.32	925.08	925.22

* *King County, Washington, Surface Water Design Manual*. King County Department of Natural Resources, January 24, 2005.

1-8	User input of pipe segment, discharge (Q), pipe length (L), pipe diameter (D), roughness coefficient (n), outlet elevation (El_{out}), inlet elevation (El_{in}).
9	$A = p(D/12)^2/4$
10	$V = Q/A$
11	$h_V = V^2/2g$
12	User input of tailwater elevation (El_{TW}); or $(D+d_c)/2$, whichever is greater.
13	$h_F = L(nV)^2(D/48)^{-4/3}/2.22$
14	$El_{entHGL} = El_{TW} + h_F$
15	User input of entrance headloss coefficient (K_{ent}).
16	$h_{ent} = K_{ent}V^2/2g$
17	User input of exit headloss coefficient (K_{ex}).
18	$h_{exit} = K_{ex}V^2/2g$
19	User input of other headloss coefficient (K_o).
20	$h_o = K_oV^2/2g$
21	$El_{outcont} = El_{entHGL} + h_{ent} + h_{exit}$
22	User input of inlet control elevation (El_{incon}).
23	User input of approach velocity head, $h_{AV} = h_V$ in upstream segment.
24	User input of bend headloss coefficient.
25	$h_b = K_bh_{AV}$
26	User input of upstream trunkline discharge (Q_3).
27	User input of upstream lateral discharge (Q_1).
28	$Kj = (Q_3/Q_1)/[1.18+0.63(Q_3/Q_1)]$
29	$h_j = K_jh_{AV}$
30	El_{HW} = greater of $El_{outcont}$ or $El_{incont} - h_{AV} + h_b + h_j$

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Step	Item/Description	Symbol	Unit	Calculations				
1	Pipe Segment - Outlet Structure	-	-	Outfall	O/W Sep	MH1	MH2	MH3
2	Pipe Segment - Inlet Structure	-	-	O/W Sep	MH1	MH2	MH3	MH4
3	Discharge	Q	cfs	7.00	7.00	4.20	1.96	0.84
4	Pipe Length	L	ft	42.00	10.00	364.00	164.00	100.00
5	Pipe Diameter	D	in	24	24	18	12	12
6	Manning "n" Value	n	-	0.012	0.012	0.012	0.012	0.012
7	Outlet Elevation	El_{out}	ft	919.00	919.09	919.12	919.86	920.70
8	Inlet Elevation	El_{in}	ft	919.09	919.12	919.86	920.70	921.22
9	Barrel Area	A	ft^2	3.14	3.14	1.77	0.79	0.79
10	Barrel Velocity	V	ft/sec	2.23	2.23	2.38	2.50	1.07
11	Barrel Velocity Head	h_V	ft	0.08	0.08	0.09	0.10	0.02
12	Tailwater Elevation	El_{TW}	ft	920.47	920.56	920.16	920.65	921.38
13	Friction Loss	h_f	ft	0.03	0.01	0.49	0.42	0.05
14	Entrance Hydraulic Grade Elevation	El_{entHGL}	ft	921.09	921.12	921.36	921.70	922.22
15	Entrance Loss Coefficient	K_{ent}	-	0.50	0.50	0.50	0.50	0.50
16	Entrance Head Loss	h_{ent}	ft	0.04	0.04	0.04	0.05	0.01
17	Exit Loss Coefficient	K_{ex}	-	1.00	1.00	1.00	1.00	1.00
18	Exit Head Loss	h_{ex}	ft	0.08	0.08	0.09	0.10	0.02
19	Other Loss Coefficient	K_o	-	5.00	0.00	0.00	0.00	0.00
20	Other Head Loss	h_o	ft	0.39	0.00	0.00	0.00	0.00
21	Outlet Control Elevation	$El_{outcont}$	ft	921.59	921.24	921.49	921.85	922.25
22	Inlet Control Elevation	El_{incont}	ft	920.44	920.07	921.00	921.35	921.77
23	Approach Velocity Head	h_{AV}	ft	0.00	0.00	0.00	0.00	0.00
24	Bend Loss Coefficient	K_b	-	0.00	0.00	0.00	0.00	0.00
25	Bend Head Loss	h_b	ft	0.00	0.00	0.00	0.00	0.00
26	Upstream Trunkline Discharge	Q_1	cfs	7.00	7.00	4.20	1.96	0.84
27	Upstream Lateral Discharge	Q_3	cfs	0.00	0.00	2.80	2.24	0.00
28	Junction Loss Coefficient	K_j	-	0.00	0.00	0.42	0.60	0.00
29	Junction Head Loss	h_j	ft	0.00	0.00	0.00	0.00	0.00
30	Headwater Elevation	El_{HW}	ft	921.59	921.24	921.49	921.85	922.25

* *King County, Washington, Surface Water Design Manual*. King County Department of Natural Resources, January 24, 2005.

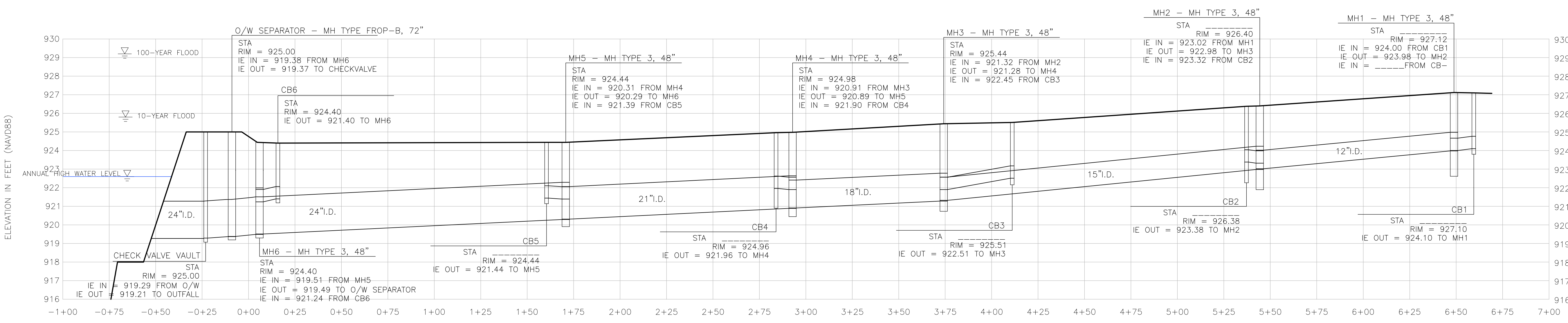
1-8	User input of pipe segment, discharge (Q), pipe length (L), pipe diameter (D), roughness coefficient (n), outlet elevation (El_{out}), inlet elevation (El_{in}).
9	$A = p(D/12)^2/4$
10	$V = Q/A$
11	$h_V = V^2/2g$
12	User input of tailwater elevation (El_{TW}); or $(D+d_c)/2$, whichever is greater.
13	$h_F = L(nV)^2(D/48)^{-4/3}/2.22$
14	$El_{entHGL} = El_{TW} + h_F$
15	User input of entrance headloss coefficient (K_{ent}).
16	$h_{ent} = K_{ent}V^2/2g$
17	User input of exit headloss coefficient (K_{ex}).
18	$h_{exit} = K_{ex}V^2/2g$
19	User input of other headloss coefficient (K_o).
20	$h_o = K_oV^2/2g$
21	$El_{outcont} = El_{entHGL} + h_{ent} + h_{exit}$
22	User input of inlet control elevation (El_{incon}).
23	User input of approach velocity head, $h_{AV} = h_V$ in upstream segment.
24	User input of bend headloss coefficient.
25	$h_b = K_bh_{AV}$
26	User input of upstream trunkline discharge (Q_3).
27	User input of upstream lateral discharge (Q_1).
28	$Kj = (Q_3/Q_1)/[1.18+0.63(Q_3/Q_1)]$
29	$h_j = K_jh_{AV}$
30	El_{HW} = greater of $El_{outcont}$ or $El_{incont} - h_{AV} + h_b + h_j$

King County *Surface Water Design Manual* (2005)* Backwater Calculation

Step	Item/Description	Symbol	Unit	Calculations						
1	Pipe Segment - Outlet Structure	-	-	Outfall	O/W Sep	MH1	MH2	MH3	MH4	MH5
2	Pipe Segment - Inlet Structure	-	-	O/W Sep	MH1	MH2	MH3	MH4	MH5	MH6
3	Discharge	Q	cfs	7.00	7.00	5.11	4.20	3.29	1.96	0.84
4	Pipe Length	L	ft	42.00	10.00	160.00	118.00	78.00	164.00	100.00
5	Pipe Diameter	D	in	24	24	18	18	18	12	12
6	Manning "n" Value	n	-	0.012	0.012	0.012	0.012	0.012	0.012	0.012
7	Outlet Elevation	El_{out}	ft	919.00	919.09	919.12	919.45	919.69	919.85	920.69
8	Inlet Elevation	El_{in}	ft	919.09	919.12	919.45	919.69	919.85	920.69	921.21
9	Barrel Area	A	ft^2	3.14	3.14	1.77	1.77	1.77	0.79	0.79
10	Barrel Velocity	V	ft/sec	2.23	2.23	2.89	2.38	1.86	2.50	1.07
11	Barrel Velocity Head	h_V	ft	0.08	0.08	0.13	0.09	0.05	0.10	0.02
12	Tailwater Elevation	El_{TW}	ft	920.47	920.56	920.31	920.58	920.78	920.64	921.38
13	Friction Loss	h_f	ft	0.03	0.01	0.32	0.16	0.06	0.42	0.05
14	Entrance Hydraulic Grade Elevation	El_{entHGL}	ft	921.09	921.12	920.95	921.19	921.35	921.69	922.21
15	Entrance Loss Coefficient	K_{ent}	-	0.50	0.50	0.50	0.50	0.50	1.50	2.50
16	Entrance Head Loss	h_{ent}	ft	0.04	0.04	0.06	0.04	0.03	0.15	0.04
17	Exit Loss Coefficient	K_{ex}	-	1.00	1.00	1.00	1.00	1.00	2.00	3.00
18	Exit Head Loss	h_{ex}	ft	0.08	0.08	0.13	0.09	0.05	0.19	0.05
19	Other Loss Coefficient	K_o	-	5.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Other Head Loss	h_o	ft	0.39	0.00	0.00	0.00	0.00	0.00	0.00
21	Outlet Control Elevation	$El_{outcont}$	ft	921.59	921.24	921.14	921.32	921.43	922.03	922.31
22	Inlet Control Elevation	El_{incont}	ft	921.09	921.12	920.95	921.19	922.35	921.69	922.21
23	Approach Velocity Head	h_{AV}	ft	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Bend Loss Coefficient	K_b	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Bend Head Loss	h_b	ft	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Upstream Trunkline Discharge	Q_1	cfs	7.00	5.11	4.20	3.29	1.96	0.84	0.84
27	Upstream Lateral Discharge	Q_3	cfs	0.00	1.89	0.91	0.91	1.33	1.12	0.00
28	Junction Loss Coefficient	K_j	-	0.00	0.26	0.16	0.20	0.42	0.66	0.00
29	Junction Head Loss	h_j	ft	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	Headwater Elevation	El_{HW}	ft	921.59	921.24	921.14	921.32	922.35	922.03	922.31

* *King County, Washington, Surface Water Design Manual*. King County Department of Natural Resources, January 24, 2005.

1-8	User input of pipe segment, discharge (Q), pipe length (L), pipe diameter (D), roughness coefficient (n), outlet elevation (El_{out}), inlet elevation (El_{in}).
9	$A = p(D/12)^2/4$
10	$V = Q/A$
11	$h_V = V^2/2g$
12	User input of tailwater elevation (El_{TW}); or $(D+d_c)/2$, whichever is greater.
13	$h_F = L(nV)^2(D/48)^{-4/3}/2.22$
14	$El_{entHGL} = El_{TW} + h_F$
15	User input of entrance headloss coefficient (K_{ent}).
16	$h_{ent} = K_{ent}V^2/2g$
17	User input of exit headloss coefficient (K_{ex}).
18	$h_{exit} = K_{ex}V^2/2g$
19	User input of other headloss coefficient (K_o).
20	$h_o = K_oV^2/2g$
21	$El_{outcont} = El_{entHGL} + h_{ent} + h_{exit}$
22	User input of inlet control elevation (El_{incon}).
23	User input of approach velocity head, $h_{AV} = h_V$ in upstream segment.
24	User input of bend headloss coefficient.
25	$h_b = K_bh_{AV}$
26	User input of upstream trunkline discharge (Q_3).
27	User input of upstream lateral discharge (Q_1).
28	$Kj = (Q_3/Q_1)/[1.18+0.63(Q_3/Q_1)]$
29	$h_j = K_jh_{AV}$
30	El_{HW} = greater of $El_{outcont}$ or $El_{incont} - h_{AV} + h_b + h_j$



15 0 30
HORIZONTAL SCALE IN FEET
VERTICAL EXAGGERATION: 10X

60% DRAWINGS - NOT FOR CONSTRUCTION

RETEC

NO	DRWN	DATE	REVISION	CHKD	DATE	APPVD	DATE
5							
4							
3							
2							
1	A.S.	8/9/05	60% DRAWINGS	J.S.	8/9/05		
0	A.S.	2/23/05	30% DRAWINGS	J.S.	2/23/05	J.S.	2/23/05

THE BNSF RAILWAY COMPANY
SKYKOMISH, WASHINGTON
BN050-16423-520

CURRENT DATE 12/20/05

SKYKOMISH LEVEE REMEDIATION

FINAL STORM SEWER PROFILE

DRAWING NO. FIGURE 1

REVISION

File: H:\16423\DESIGN SET\60% DRAWINGS\BN050-16423-CE-ST-5030.dwg Layout: C-17 User: astenberg Plotted: Dec 23, 2005 - 12:21pm Xref's: BN050-16423-CE-ST-B003, storm-system, NEW-BERM-2-CONST

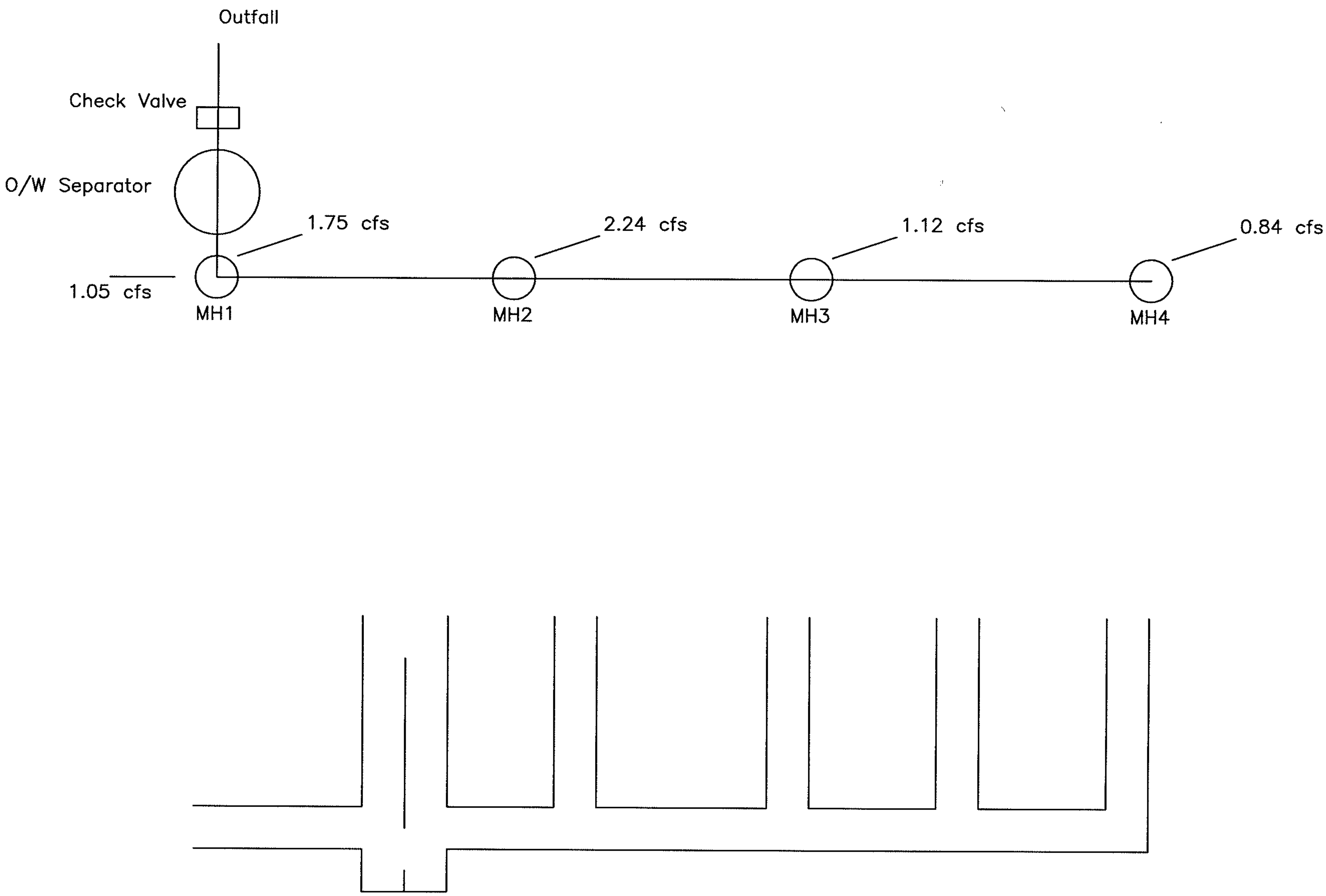


Figure 2. Schematic Plan and Profile of the Four–Manhole Configuration.

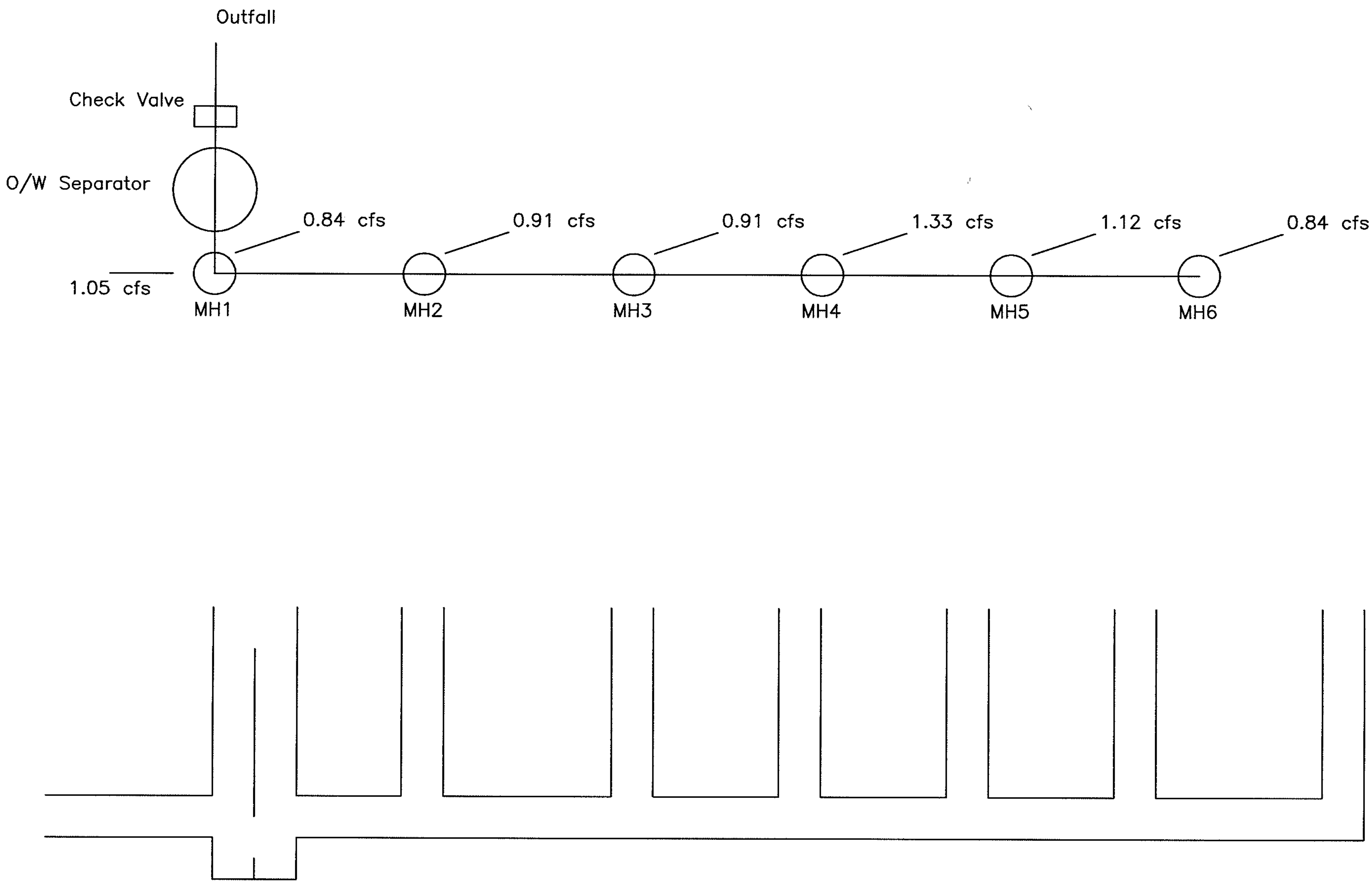


Figure 3. Schematic Plan and Profile of the Six–Manhole Configuration.